



Development of Advanced Life Prediction Tools for Elastic-Plastic Fatigue Crack Growth

NASGRO

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Objective

A systematic approach to improving the fracture control process, including analytical tools, standards, guidelines, and awareness

Focus on Analytical Tool Development

Analytical tools specifically for elastic-plastic fracture analysis -- a regime that is currently empirical for the Space Shuttle External Tank (ET) and handled by simulated service testing of pre-cracked panels.

- Continue development of advanced fracture mechanics analysis tools for determining the life of components which experience severe low cycle load environments.
- Address recurring life assessment and fracture control issues for which no general analysis tools are available.



Recurring Safety Needs



Fracture Control is an integral part of manned space flight safety.

- **Shuttle Independent Assessment Team Observations**

- ... Many aging aircraft practices and techniques are directly applicable to Shuttle.

- More accurate structural life prediction and inspection methods have been developed since the design and early maintenance of the Shuttle and should be pursued...** Because no redundancy exists for much of the Orbiter structure and many mechanical components (e.g., landing gear), structural maintenance and inspection processes can significantly impact Shuttle safety ...

- **Shuttle (:ET) will be the primary manned space flight vehicle for the next 10 years –**

- ET fracture behavior warrants continued and improved understanding



Improved Understanding



Current ET approach is sound, firmly grounded in an empirical database; however, advances in fracture mechanics may offer additional benefits.

- Understanding of simulated service test behavior
 - Ductile tearing during proof and flight
 - Elastic-plastic fatigue crack growth
- Evaluation of multi-cycle proof effects
- More accurate critical flaw size estimates and evaluation of defects screened by proof

Practical analytical tools are needed to realize these advances and complement the empirical approach.



Goal

Provide MSFC and the Agency with Advanced Modeling and Simulation Capabilities for LCF Crack Growth Assessment

How to achieve the goal

Pursue these basic elements of advanced tool development for NASGRO

- Cyclic elastic-plastic material behavior effects
- Crack growth in low cycle fatigue



Previous Development

- NASA-Marshall technology programs to develop new engineering methods
- Three major contracts funded through ETO and LTHP over past 10 years
 - “A Comparison of Single-Cycle vs. Multiple-Cycle Proof Testing”
(NAS8-37451)
 - “Proof Test Philosophy to State-of-the-Art Technology”
(NAS8-39380)
 - “Elastic-Plastic and Fully-Plastic Fatigue Crack Growth”
(NAS8-37828)
- Southwest Research Institute was prime contractor on all three programs
 - Some subcontract support from Rocketdyne
- All three contracts successful in developing practical engineering methods



Previous Development

Why NASGRO?

- NASA/Industry standard for safe-life fracture control assessments
 - NASA, ESA, FAA, Air Force, Contractors, Nuclear Power
 - Massive investment in NASGRO for payloads, vehicle structures
 - Substantial material database in place
- Current NASGRO code provides baseline for elastic-plastic framework
- Proposed modules use some existing NASGRO solutions and materials
- Elementary elastic-plastic modules previously developed for 5 crack geometries
 - TC01: Through crack crack; tension
 - TC02: Through edge crack; tension, bending
 - EC01: Embedded elliptical crack; tension
 - CC01: Corner crack in rectangular plate; tension, bending
 - SC01: Surface crack in rectangular plate; tension, bending
- Baseline modules to be released in NASGRO 4.0
 - Verification completed for Inconel 718
 - Verification planned for Al 2219



NASGRO Modules



Space Shuttle ET Program Support

- Proof Test Analysis Module
 - Implement procedures in Proof Test Analysis Guidelines
 - User-friendly driver to aid step-by-step analysis road map
- Failure Analysis Module
 - Current capabilities limited to assessments at one-crack tip position
 - Need assessments at multiple-crack tip positions to address complex crack shapes, stress gradients
 - Particularly important for proof test analysis
- Surface Crack Solution Module
 - Implement new J solutions for NASGRO SC02, SC04 geometries
 - Surface cracks in plates (SC02) and cylinders (SC04) with arbitrary non-linear stress gradient
 - Cylindrical geometries are particularly important for proof test analysis



NASGRO Modules



Space Shuttle ET Program Support

- Multiple Cycle Proof Test (MCPT) Analysis Module
 - Implement procedures for MCPT reliability analysis
 - Includes simple probabilistic driver for distributions of initial crack size
- Tear-Fatigue Module
 - Implement practical algorithms for crack growth near instability
 - Tear-fatigue capability essential for MCPT analysis
- Embedded Crack Solution Module
 - Current NASGRO EC solution very limited
 - Implement improved EC solution to address stress gradients, off-center cracks\
- Further work in propulsion systems may include efforts on combined primary-secondary load effects



Participants

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* MSFC Fracture Control Board

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Results and Benefits

- These modules can provide benefits such as more accurate life assessments, longer inspection intervals and improved critical initial flaw size estimates, but they are not intended to change current philosophies preserving flight safety.
- MSFC will obtain analytical tools applicable in the assessment of problems that are currently untenable
- MSFC will develop new in-house fracture mechanics expertise, reinforcing a dwindling Agency capability
- The industry will benefit from the development of a practical analytical tool for advanced fracture analysis

